Alternative: Removal of Trace Constituents from Groundwater

1. Summary of the Alternative

Groundwater that would otherwise be potable may require removal of trace constituents prior to consumption. Some such constituents (e.g., arsenic) may occur naturally in the groundwater, while others (e.g., trichloroethylene [TCE]) may be of anthropogenic origin. Trace constituents that commonly occur in New Mexico groundwater at concentrations that exceed drinking water standards include arsenic, iron, manganese, nitrate, radium, and uranium. EPA's primary maximum contaminant levels (MCLs), which must be met by all public water supplies, for these constituents are listed in Table 1.

**Table 1. Drinking Water Standards for
Selected Trace Constituents**

Constituent	EPA MCL [a]
Arsenic	10 µg/L [b]
Iron	0.3 mg/L [c]
Manganese	0.05 mg/L [c]
Nitrate (as N)	10 mg/L
Radium	5 pCi/L
Uranium	30 µg/L [d]
Gross alpha radiation	15 pCi/L

[a] Pursuant to the Safe Drinking Water Act, 42 U.S.C. 300f *et seq.*
[b] New arsenic MCL becomes effective in January 2006.
[c] Secondary (non-enforceable) standard established for aesthetic reasons.
[d] New uranium MCL takes effect December 8, 2003.

According to the Jemez y Sangre water planning study (DE&S, 2001), elevated concentrations of each of the above constituents can be found in groundwater at isolated locations within the study area. Additional constituents reportedly found at elevated concentrations in particular

wells include barium, fluoride, and sulfate, plus miscellaneous organic compounds associated with leaking underground storage tanks and spills, such as benzene, toluene, TCE, and perchloroethylene (PCE) (DE&S, 2001).

DBS&A used a northern New Mexico water quality database compiled by Los Alamos National Laboratories to determine which constituents are most often present in groundwater at concentrations above their respective MCLs. Figure 1 shows the wells within the study area that have exceeded drinking water MCLs for one or more constituents. As shown in the figure, arsenic appears to be the constituent that most commonly exceeds MCLs within the study area. Therefore, the focus of the remainder of this paper is on arsenic treatment to meet the new MCL of 10 µg/L. Many of the same technologies used for arsenic treatment are also applicable to the removal of the other constituents, such as dissolved iron, manganese, and uranium.

Because of the regulatory requirements, particularly for arsenic, the removal of trace constituents is necessary to use existing supplies and does not provide new water to meet growing demand.
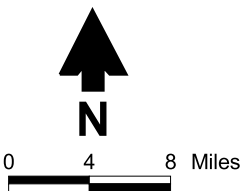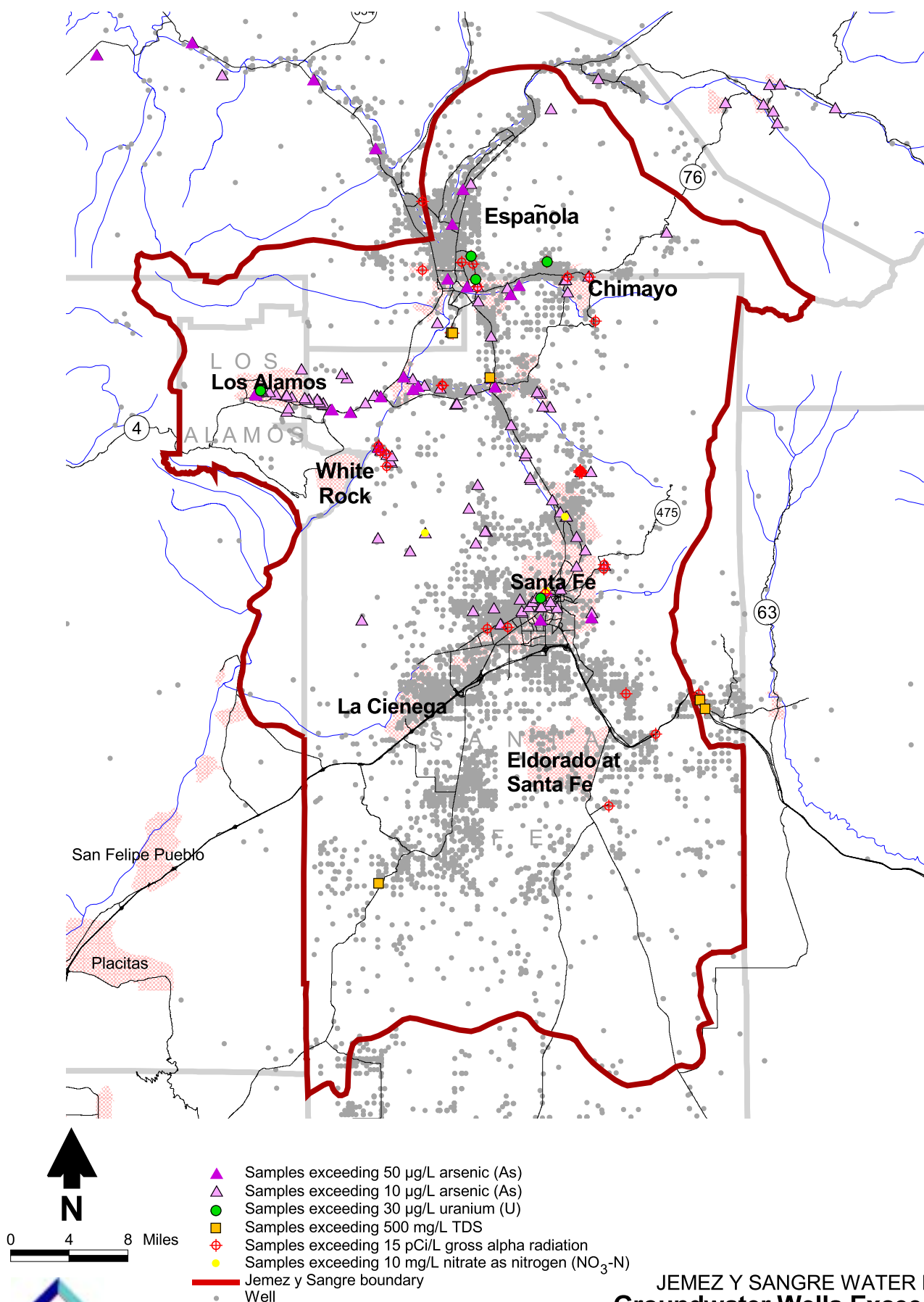
2. Technical Feasibility

In January 2001, the U.S. Environmental Protection Agency (EPA) lowered the arsenic drinking water standard from 50 µg/L to 10 µg/L. The new standard applies to both community water systems and non-transient, non-community water systems. Public drinking water supplies must comply with the new 10-ppb arsenic MCL within five years of promulgation of the new rule, that is, on or before January 22, 2006. However, certain provisions for extensions due to technical or economic hardship are available.

It is well known that elevated concentrations of naturally occurring arsenic are present in groundwater throughout much of northern New Mexico (DE&S, 2001). The previous arsenic MCL of 50 µg/L is exceeded in numerous wells in northern New Mexico (Figure 1), and many more wells exceed the new arsenic standard of 10 µg/L (Figure 1). Therefore, at some locations within the study area, arsenic removal will be required prior to serving groundwater to consumers.

Españolã

Chimayo

LOS

Los Alamos

ALAMOS

White
Rock

Santa Fe

La Cienega

Eldorado at
Santa Fe

S A N

F E

San Felipe Pueblo

Placitas

N

0   4   8 Miles

▲ Samples exceeding 50 µg/L arsenic (As)
△ Samples exceeding 10 µg/L arsenic (As)
● Samples exceeding 30 µg/L uranium (U)
■ Samples exceeding 500 mg/L TDS
⊕ Samples exceeding 15 pCi/L gross alpha radiation
● Samples exceeding 10 mg/L nitrate as nitrogen (NO$_3$-N)
━━ Jemez y Sangre boundary
• Well

S:\PROJECTS\9419\GIS\PROJECT (PROJECT = BASE_MAP.APR) (VIEW EXTENTS = 1:600,000) (VIEW NAME = V4) (LAYOUT = L4-Wells Exceeding MCLs, A-size, 1:600,000)

JEMEZ Y SANGRE WATER PLAN
**Groundwater Wells Exceeding
Drinking Water Standards**

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Figure 1

Unlike desalination, treatment of water to reduce arsenic concentrations is relatively new. The technologies for arsenic removal are still evolving rapidly, and technology breakthroughs are likely over the coming years. Both EPA and the American Water Works Association Research Foundation (AWWARF) have investigated the technologies available for removal of arsenic from groundwater and are supporting the development of new technologies.

EPA identified the following types of processes as being applicable to the removal of arsenic from drinking water (U.S. EPA, 2000):

- Precipitation processes (e.g., coagulation/filtration, lime softening, etc.)
- Sorption processes (e.g., activated alumina)
- Ion exchange processes
- Membrane processes (e.g., nanofiltration, reverse osmosis [RO])
- Alternative technologies

AWWARF (Amy et al., 2000) identified the following technologies as most promising for aboveground arsenic removal: (1) sorption on activated alumina or other solid media, (2) ion exchange, (3) coagulation/microfiltration, and (4) nanofiltration/reverse osmosis. One of these technologies may prove superior to the others in any particular situation, depending largely on the size of the treatment system and flow rate.

2.1   Activated Alumina

The activated alumina process involves adsorption of arsenic on a filter bed of oxidized alumina (Al_2O_3). When the alumina surface becomes exhausted, it must be regenerated using a strong base solution, such as sodium hydroxide. The alumina is then rinsed with water, and the high pH is neutralized using an acid solution. The strong base regenerant solution must be disposed of, and eventually the alumina bed must be replaced. As an alternative, the alumina is not regenerated but rather disposed of directly when spent ("throwaway activated alumina").

2.2 Ion Exchange

Ion exchange is an adsorption process in which dissolved arsenic in the water becomes adsorbed to a synthetic-coated plastic resin. For each negatively charged arsenate anion that becomes adsorbed, one chloride ion is liberated, thus the name ion exchange. Ion exchange can continue until the resin is exhausted, at which point it must be regenerated by passing a concentrated chloride salt solution (brine) over the resin, which displaces the arsenate ions and replenishes the chloride ions on the resin (CH2M-Hill, 1999). The brine can be reused many times prior to disposal, but will then contain appreciable concentrations of dissolved arsenic.

Because sulfate is adsorbed preferentially over arsenate, elevated sulfate concentrations in the feedwater will result in shorter times before the ion exchange resin becomes exhausted. Another potential drawback of ion exchange is the possibility of "chromatographic breakthrough," which could result in rapid release of the sorbed arsenic from the ion exchange resin back to the treated water.

2.3 Coagulation/Microfiltration

This technology involves the addition to the feedwater of a chemical (e.g., ferric chloride), which then precipitates (as ferric hydroxide) and causes co-precipitation of dissolved arsenic. The precipitate with adsorbed arsenic is then removed by flocculation and gravity settling, or by filtration. Because of the high affinity of the dissolved arsenate anion for the ferric hydroxide surface, coagulation/microfiltration can achieve very high removal efficiencies. Pentavalent arsenic (As V) is removed more effectively than trivalent arsenic (As III) species. Microfiltration is necessary to remove the fine ferric hydroxide particles quickly.

The process uses significant amounts of chemical reagents to remove the arsenic from the water, and these chemicals accumulate as an arsenic-bearing sludge that must be disposed of in a permitted landfill. The transportation of chemicals and sludge to and from the treatment plant is an important cost consideration for this technology.

2.4   Reverse Osmosis

RO involves forcing water through a semipermeable membrane.   The white paper on desalination (DBS&A, 2002) provides more information on the RO technology.   RO not only removes arsenic from the water, but most other dissolved ions as well.   Thus RO reduces both the arsenic concentration and the total dissolved solids (TDS) content of the water.   Because of the high energy demand, RO would in most cases not be the most cost-effective means of arsenic removal.   An exception would be if the water supply also required treatment to reduce salinity levels, in which case, RO could be used to simultaneously effect both salinity reduction and arsenic removal.   A potential drawback of RO is its inability to remove uncharged As III species without prior oxidation to As V.

2.5   Subsurface Arsenic Treatment

Subsurface arsenic treatment is an innovative and potentially cost-effective technology for arsenic treatment at the wellhead (Miller, 2001).   The concept is to create a geochemical barrier composed of iron hydroxide in the aquifer surrounding the well.   The iron hydroxide surfaces will adsorb dissolved arsenic as it approaches the well screen, thereby removing it from solution. The geochemical barrier can be created either by injection of a ferric solution followed by oxygenated water or by alternating injection and withdrawal of oxygenated water to and from the well.   While subsurface arsenic removal has not yet been demonstrated on a large scale, it offers the significant advantages that the arsenic in the groundwater is left below ground, no arsenic-bearing waste sludges or waste chemical solutions requiring disposal are generated, and minimal operator training is required.

2.6   Selection of Preferred Arsenic Treatment Technology

Many factors must be considered in selecting the most appropriate arsenic treatment technology for a given site, including feedwater arsenic concentration, total flow rate, general water chemistry, and proximity to an approved disposal site for waste sludge.   Another consideration is whether the situation requires numerous separate treatment facilities or a single large facility.   In Albuquerque, for example, the dispersed locations of City supply wells, coupled

with the large elevation difference between them, requires that arsenic treatment systems be installed at each wellhead or storage tank, as opposed to a single large treatment plant (Chwirka et al., 2000). Because this restriction limits the possibility of economy of scale, certain technologies are more favorable than others.

Small communities (fewer than 3,000 persons) may be able to use point-of-use, ion exchange, or RO systems to remove arsenic within the home. However, treatment costs for small systems will always be higher per household served (Gurian and Small, 2002). Therefore, where feasible, "regionalization" of water treatment systems is to the consumer's benefit.

A further consideration in selecting the preferred technology for a given site is water waste. Some technologies, such as RO, result in a large wastewater stream whereas others, such as activated alumina adsorption or coagulation/microfiltration, waste very little water (Chwirka et al., 2000). Last but not least, waste management of residuals (e.g., sludge, spent filter media) is a significant cost consideration for some of the technologies, such as coagulation/ microfiltration and ion exchange.

3. Financial Feasibility

Over the past few years, many New Mexico communities that rely on groundwater have been concerned about the costs of future arsenic treatment when the new MCL goes into effect. While federal funding may become available to assist communities in complying with the new drinking water standard, operation and maintenance costs for arsenic treatment plants will ultimately be passed on to customers. Bitner (2001) has investigated anticipated arsenic treatment costs in New Mexico and found that in addition to the other variables mentioned in Section 2.6, the most cost-effective technology for arsenic treatment at a particular location will depend largely on system capacity. For example, RO may prove the most cost-effective for small point-of-use systems, whereas large public water supplies may find the coagulation/ microfiltration technology most economical.

The American Water Works Association (AWWA) arsenic work group developed an *Arsenic Treatment Cost Estimating Tool* to help communities estimate their costs to comply with the new drinking water standard (AWWARF, 2000; Chwirka and Narasimhan, 2000). The tool consists of an Excel spreadsheet into which are entered the raw water arsenic concentration and flow rate, interest rate, and other variables. The tool permits calculation of capital and operations and maintenance (O&M) costs, as well as monthly rate increases that can be expected by customers. An updated cost tool is expected to be released by AWWA by Summer 2002.

CH2M-Hill (1999) has investigated arsenic treatment costs for the City of Albuquerque. This evaluation ranked three technologies (activated alumina, ion exchange, and coagulation/ microfiltration) in terms of costs and ease of implementation in Albuquerque. The report concluded that coagulation/microfiltration is the preferred technology for Albuquerque. Ion exchange was rejected because of the large volumes of generated waste brine and salt that would require disposal.

4. Legal Feasibility

All water to be used for municipal supplies must be treated to comply with Safe Drinking Water Act standards (42 U.S.C. 300f *et seq.*) and New Mexico's drinking water regulations found at 20 NMAC 7.1. The legal restraints associated with the disposal of any brine generated through the process of treating water include the permitting requirements necessitated by discharge to groundwater, surface water, or landfills (Section 6).

5. Effectiveness in Either Increasing the Available Supply or Reducing the Projected Demand

All of the technologies described above are very effective in removing dissolved arsenic to levels well below the new MCL of 10 µg/L. Typically only a portion of the water supply would be treated, but the resulting arsenic concentrations would be very low (e.g., <1 µg/L). This essentially "arsenic free" treated water would then be blended with untreated groundwater in

proportions that would ensure that the resulting blend would still be below the arsenic MCL. Blending in this way reduces overall treatment costs.

No new supply would actually be created by this alternative, but treatment would allow water users to exercise their water rights. The City of Española has several wells off-line due to high fluoride and other trace constituents. If the communities create a regional water system, the ability to cost-effectively remove arsenic nitrate, uranium, and other trace constituents would be vastly improved.

6. Environmental Implications

The primary environmental concern for arsenic treatment (and treatment to remove other trace constituents) involves the management of waste residuals, such as RO brine, coagulation/ microfiltration sludge, or spent ion exchange resins. Generation and disposal of RO brine (highly concentrated saline water) may be undesirable, both from an economic perspective (permitting costs), as well as a public perception standpoint. Alternatives for disposal of brine include (1) deep subsurface injection, (2) discharge to surface water stream or lake, (3) discharge to sanitary sewer, (4) discharge to evaporation ponds, and (5) evaporation, crystallization, and disposal of solid salt in a special landfill:

- Deep subsurface injection would require a Class V well permit from the NMED Underground Injection Control (UIC) Program, which could be costly to obtain. Furthermore, deep injection wells would have to be drilled and maintained, which would also prove costly.

- Direct discharge of brine to surface water bodies would require an approved National Pollutant Discharge Elimination System (NPDES) permit, and in all likelihood this option would not be permitted because it would result in degradation of surface water quality.

- Brine disposal to sanitary sewers probably would not require a permit providing the quantities were small enough to not cause significant salinity change in total flow to the

wastewater treatment plant. For small desalination plants in communities served by sewers, this could prove the most economical option for brine disposal.

- Disposal of brine in lined evaporation ponds can be relatively inexpensive, especially where land is readily available. Brine evaporation ponds operating in Texas add costs of $0.05 to $0.25 per 1,000 gallons of fresh water produced (U.S. Congress, 1988).

- Crystallization and disposal of salts in an approved landfill may be the preferred option, in part due to the high technical and regulatory costs of surface or subsurface brine disposal.

Solid wastes generated by the alumina absorption, coagulation/microfiltration, or ion exchange processes would require disposal in a permitted landfill. The most important consideration would be whether the waste sludge or solids would be classified as a hazardous waste under RCRA regulations. This determination would be based on the results of laboratory testing using the Toxicity Characteristic Leaching Procedure (TCLP). This test involves leaching of the waste material in a weak acid solution and subsequent testing of the TCLP extract to determine if the arsenic concentration exceeds the TCLP limit of 5 mg/L. If the waste fails the TCLP test, then that waste would be classified as a RCRA hazardous waste based on the toxicity characteristic for arsenic. Whether a particular waste material passes or fails the TCLP test would thus depend both on the concentration of arsenic it contains and the extent to which the arsenic is soluble in the TCLP test. This regulation would also apply to waste products generated from treatment processes to remove trace constituents other than arsenic.

Wastes that pass the TCLP test would be classified as non-hazardous municipal waste and could potentially be disposed of at any Subtitle D municipal landfill at costs of approximately $25 per ton tipping fee. However, such wastes might be considered to be "special waste" under the New Mexico solid waste management regulations, requiring segregation in a separate designated portion of the landfill. This determination would be made by the NMED Solid Waste Bureau.

If the waste failed the TCLP test, it would be classified as a RCRA hazardous waste based on the toxicity characteristic for arsenic, which would in turn radically increase disposal costs. Such a classification would require that the waste be disposed at an out-of-state RCRA hazardous waste landfill at a cost that could exceed $1,000 per ton, not including transportation costs. For obvious reasons, generation of RCRA hazardous waste should be avoided if at all possible.

The preceding discussion makes it clear that disposal of waste sludge or spent reagents generated from conventional aboveground water treatment plants can constitute a large fraction of the total O&M costs. The innovative subsurface arsenic treatment technology may potentially offer large cost savings because little or no waste requiring disposal is generated. Although the feasibility of subsurface arsenic treatment at the wellhead has not yet been demonstrated, the possibility of avoiding waste disposal costs makes this alternative very attractive.

7. Socioeconomic Impacts

Treating groundwater will have no significant direct socioeconomic or cultural impacts. By making more groundwater available to more populous areas, this alternative would have the indirect socioeconomic and cultural benefit of reducing the desire for and pressure on upstream rural and agricultural surface water rights to support municipal and industrial needs.

Removal of trace constituents from all water used in the region would require the regionalization of water systems. The treatment technology is expensive and complex and therefore best effected by hiring and training skilled operators. To effectively protect all users, individual domestic well use would need to be replaced by regional wells with treatment facilities. Such regionalization could impact the independent, rural lifestyle of many water users, but could also bring in new higher paying jobs. Depending on how and by whom treatment expenses are financed, this alternative may or may not reduce the cost of water for all users.

8. Actions Needed to Implement/Ease of Implementation

Assuming that a purveyor of water has water rights, permits, and infrastructure, implementation of water treatment to remove arsenic (or other trace constituents) using aboveground treatment plants would proceed along the following general steps for planning, design, and construction:

1. Conceptual design/feasibility study, including:

    - Assessment of treatability, blending, and waste residuals disposal

    - O&M considerations (e.g., workforce requirements)

    - Capital and annual cost estimates

    - Assessment of changes to distribution system and user rates

2. Review and approval of selected design

    - Local, state, and federal approval

    - Public participation

    - Identification of potential funding options

3. Engineering design

    - Bench studies of water compatibility

    - Development of plans and specifications

    - Preparation of bid documents for approved alternative

4. Construction (phased)

5. Preliminary O&M

6. System integration

If pilot testing indicates that this alternative is feasible, selection of the subsurface arsenic treatment technology could substantially simplify the above process because it avoids most of the design and construction steps associated with aboveground treatment plants.

The public is generally unaware of the cost implications of the new arsenic MCL. Water users in affected communities need to be educated about the new regulations and associated costs.

9. Summary of Advantages and Disadvantages

Advantages of groundwater treatment to remove trace constituents such as arsenic are:

- Enables continued use of existing well fields under new arsenic MCL, thereby maximizing community return on investment
- Increases quantity of potable water available for use through use of lower-quality water not otherwise usable without treatment
- Takes advantage of federal funding sources for arsenic treatment that are expected to become available for affected communities (e.g., SB 1299, Domenici)
- Reduces demand for low-arsenic surface water

Disadvantages of trace constituent removal from groundwater may include:

- Unit water costs are higher as compared with traditional (untreated) water sources.
- Pretreatment may be required.
- Some technologies require certified operator.
- Disposal costs for waste brine or sludge from aboveground treatment plants are likely to be high.
- Permitting requirements may be significant.
- Some innovative technologies require further testing.
- Public perception problems resulting from use of "arsenic-bearing" water may arise.

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